CONTROL OF FLUID INJECTION INTO A LOW-PERMEABILITY LAYERED RESERVOIR

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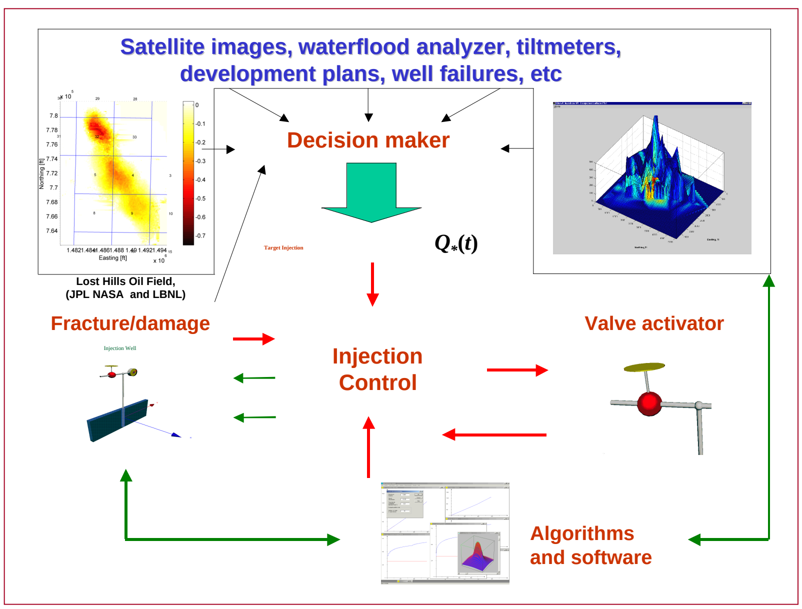
ABSTRACT

We have developed a new control model of water injection. We consider a vertically hydrofractured well in a multi-layer reservoir, where the flow in some high-permeability layers is steady-state, whereas in other layers it remains transient. We demonstrate that the optimal injection pressure depends not only on the instantaneous parameters, but also on the whole history of injection and hydrofracture and rock damage development. Based on the new model, we design an optimal injection controller that manages the rate of water injection in accordance with the changing formation properties. The control scheme includes a fracture estimate module, which has been verified against field data. In the future, the control scheme will also incorporate field-scale monitoring systems based on satellite images, tiltmeter arrays, etc.

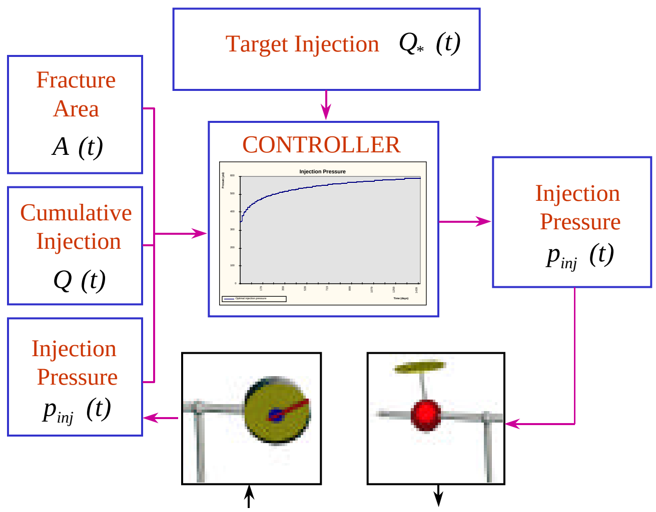


OBJECTIVES

A successful waterflood in a soft low-permeability rock is a very difficult problem. Implementation of on-line data analysis and automation of injection/production control will significantly improve the efficiency of the waterflood and decrease expenses.

Our ultimate goal is to design an integrated system of field-wide waterflood surveillance and supervisory control. Such a system consists of the Waterflood Analyzer and a network of individual injector controllers, automatic well headers and valve actuators. Field-scale monitoring data include subsidence imaging using satellites. In the future it may incorporate other technologies.

INJECTION CONTROL



The control procedure

The target injection rate is provided to the controller as an input parameter. The other input parameters are measured injection pressure, cumulative injection and an effective fracture area. By analyzing the deviation of the actual cumulative injection from the target cumulative injection, and using the measured fracture area, the controller determines the injection pressure using optimal control theory methods. The determined injection pressure is applied by adjusting a flow valve at the wellhead.

It turns out that the optimal injection pressure depends on the entire history of injection rather than only on instantaneous measurements. The convolution nature of the model does not allow us to obtain the optimal solution as a genuine feedback control and to design the controller as a standard closed-loop system. However, the feedback mode may be imitated by designing the control on a relatively short time interval, which slides with time.

Fracture/damage estimate

The effective fracture area is not available for direct measurement like the injection pressure or the injection rate. However, the controller model can be inverted in order to provide an estimate of the fracture size. This estimate can be used for designing the next control interval and passed to the controller for determining the optimal injection pressure. Therefore, obtaining this parameter does not require additional measurements.

Injection in a layered reservoir: verification of the model

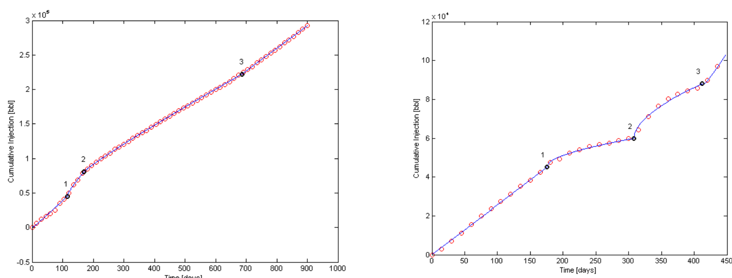
There is evidence that due to layered reservoir structure, in some layers the fluid may be transient, whereas in other layers a steady-state connection between the injector and neighboring producers is established. Using our model, we analyze the growth of the effective fracture area along with the distribution of injected fluid between steady-state and transient-flow layers.

Total injection

Transient flow | **Steady-state flow (breakthrough)**

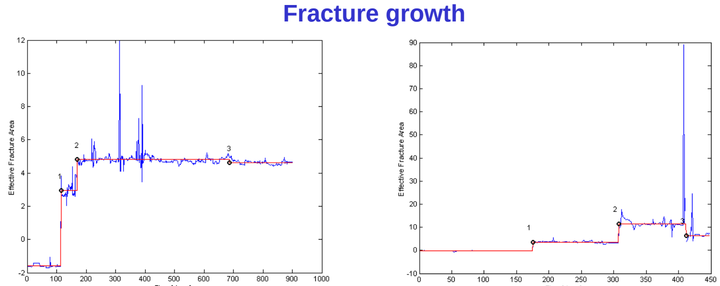
Here $_T$ means transient, $_S$ means steady-state. $(Z/Y)^2$ is a characteristic breakthrough time.

Well A **Cumulative injection** **Well B**



Verification of the model: circles = data, solid line = computations.

Fracture growth

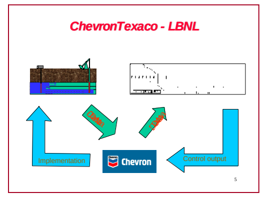


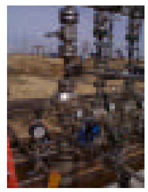
Fracture/damage propagation. Well A demonstrates behavior typical for a well with *steady state* flow. Conversely, In Well B, we recognize transient flow between points 1 and 3, with a fracture extension at point 2. A growing steady-state flow component means mostly *water circulation* after time 3.

ChevronTexaco – LBNL partnership

In 2001, ChevronTexaco, Case Services and LBNL started a pilot project in Lost Hills oil field: 12 injectors will be equipped with automatic well headers.

The data is transferred to an LBNL computer in “on-line” mode. LBNL Controller software will produce injection pressure set points, which will be implemented by the valve activators in the field.





Valve actuators

Water injection header

CONCLUSIONS

An optimal injection controller for mixed transient/steady-state flow in a layered formation has been developed. The objective of the controller is to maintain the prescribed injection rate in the presence of hydrofracture growth and possible injector-producer linkage. The history of injection pressure and cumulative injection, along with estimates of the hydrofracture size are the controller inputs. The controller outputs an optimal injection pressure for each injector. The underlying model has been successfully verified against field data.

The controller is being implemented within a ChevronTexaco-LBNL pilot project in the Lost Hills oil field.

A global analysis of the evolution of an entire giant oilfield is possible. A shallow oilfield is treated as a large complex rock system with the coupled injectors and producers. Our evaluation shows that the satellite images are a unique source of detailed information about surface displacement over oil fields. This technology is now routinely used by oil companies in South Belridge Diatomite and the Lost Hills Diatomite, California, and will become a part of our control system.

PUBLICATIONS

- **Patzek T. W., D. B. Silin, and E. Fielding. Use of Satellite Radar Images in Surveillance and Control of Two Giant Oilfields in California. SPE Paper 71610. SPE Annual Technical Conference and Exhibition held in New Orleans, 09.30 – 10.3 2001**
- **Silin, D. B. and T. W. Patzek. Control Model of Water Injection into a Layered Formation. SPE Journal, 2001, V6(N3):253-261.**
- **Patzek, T. W. and D. B. Silin. Water injection into a low-permeability rock - 1: Hydrofracture growth. Transport in porous media. 2001, V43(N3):537-555**
- **Silin, D. B. and T. W. Patzek. Water injection into a low-permeability rock - 2: Control model. Transport in porous media. 2001, V43(N3):557-580**